The effect of pavement-watering on subsurface pavement temperatures

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Abstract: Pavement-watering is currently viewed as a potential climate change adaptation and urban heat island mitigation technique. The effects of pavement-watering on pavement temperature measured 5 cm deep are presented and discussed. Subsurface temperature measurements could not be used to improve or optimize pavement-watering methods as was seen in previous work on surface temperatures or subsurface pavement heat flux measurements.

1. Introduction

While evaporative cooling has been used in warm regions for centuries, pavement-watering has gained renewed interest in recent years as a potential climate change adaptation and urban heat island (UHI) mitigation technique. In the last 20 years, several studies have been conducted in Japan [1]–[3] or elsewhere around the world [4], [5]. As climate change is predicted to increase the frequency and intensity of heat-waves in the Paris region in France [6], authorities in Paris have taken an interest on the potential benefits of a city-wide pavement-watering strategy, backed by numerical and experimental studies [7], [8].

One such field experiment of pavement-watering was conducted at two sites over the summers of 2013 and 2014 and has been extensively analyzed by the authors. Pavement heat flux and surface temperatures were used to propose improvements of the watering method applied at the Louvre site [9], [10] and the microclimatic effects of pavement-watering were studied and compared for the Louvre and Belleville sites with differing watering strategies [11].

Pavement temperature 5 cm below the surface was also measured but has not been discussed to date. We therefore propose to determine the effects of pavement-watering on pavement temperature. In addition, the potential for these measurements to be used to improve the watering method, similarly to pavement heat flux and surface temperature measurements, will also be considered.

2. Methodology

A description of the test site, instrument installation, and watering method used for this study can be found in Hendel et al. [9].

The pavement sensor described in that paper and used to measure pavement heat flux also includes a Type T thermocouple used to record pavement temperature 5 cm below its surface discussed here. As was the case for pavement heat flux, pavement temperature was recorded every minute in local daylight savings time (UTC +2).

3. Results

Figure 1 illustrates pavement temperature measurements 5 cm below the surface on July 7th, 8th, 10th, 11th, 20th and 22nd. Dot-dashed lines indicate watering cycles. July 7th, 11th and 20th are used as control days and paired with the watered days July 8th, 10th and 22nd for comparison and analysis of pavement-watering effects.

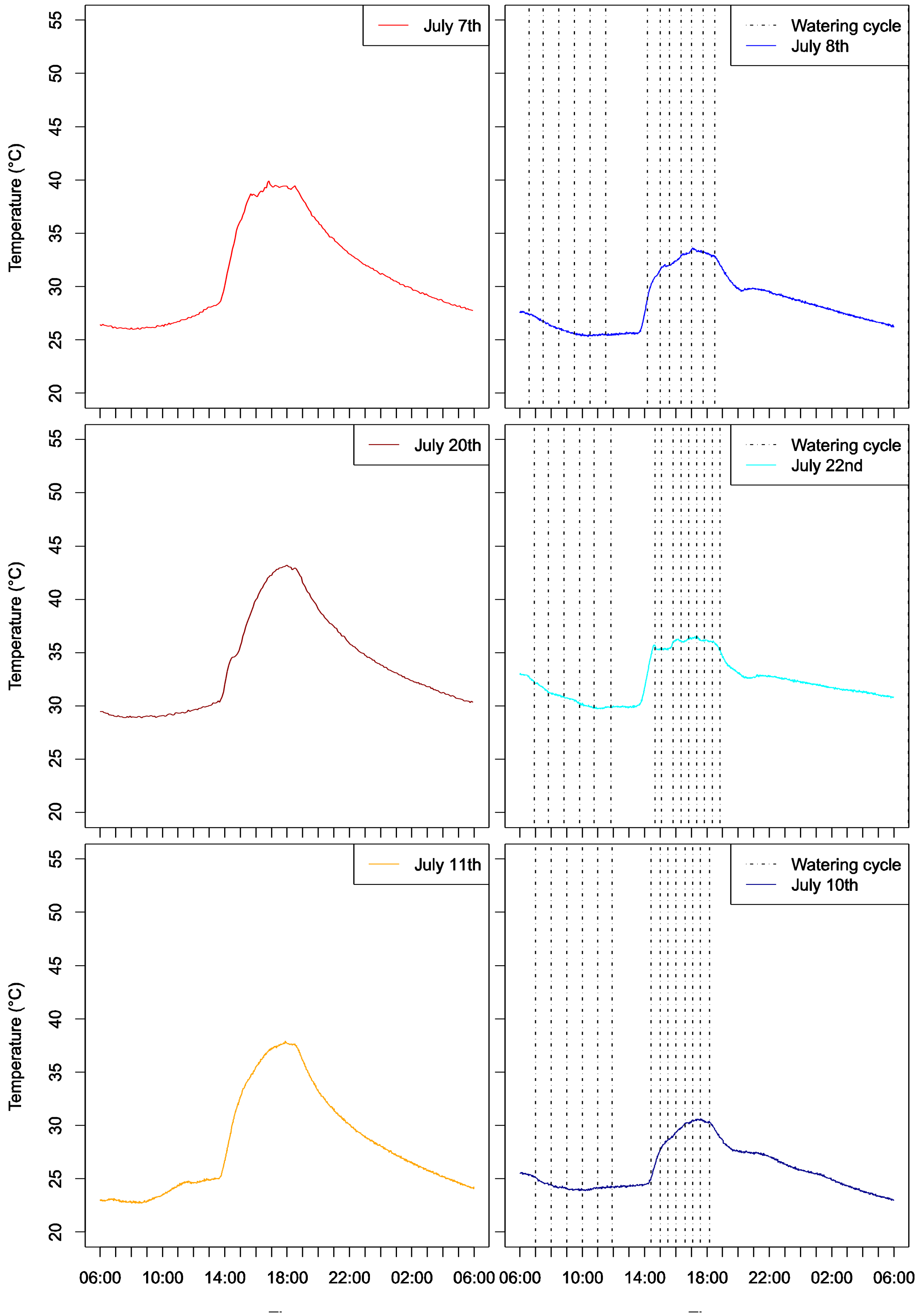

Figure 1: *Pavement temperature 5 cm below the surface on control days (left) and watered days (right) measured in July 2013*

On control days, pavement temperatures range from a low of 23°-29°C to a high of 38°-43°C. The average temperature amplitude on control days is approximately 14.6°C. Temperatures decrease by 0.5°C on average from 6 am until approximately 8 am when they reach their daily low value. They then slowly increase until pavement insolation begins at 1:35 pm. At that time, temperatures rise sharply and level off at their daily maximum about one hour before insolation ends at 6:30 pm. Pavement temperatures then decrease until the next day when the cycle restarts.

On watered days, this range is reduced to between 23°-30°C and 31°-37°C. The daily temperature amplitude is nearly halved, averaging approximately 7.7°C. Compared to control days, morning pavement-watering significantly increases and prolongs the temperature decrease phase until 1:35 pm. The morning temperature drop is increased to 2.8°Con average. As a result, daily minimum temperatures are practically unchanged compared to control days despite higher temperatures at 6 am, before morning watering. In the afternoon, the temperature increase is significantly shortened, leveling off much sooner as watering resumes. The time at which the daily high temperature is reached is unchanged by watering. As pavement insolation ends, temperatures decrease until the end of the day. In all the watered days considered here, an interruption in this decrease occurs about 2.5h after sunset, as the remaining water film completely evaporates from the pavement surface.

Mean temperatures from 3 pm to 6:30 pm are reduced by 6°C on July 8th compared to July 7th,by 5°C on July 22nd compared to July 20th, and by 6.5°C on July 10th compared to July 11th.

Table 1summarizes daily low and high pavement temperatures as well as the daily temperature amplitude. Control and watered days are paired to improve comparability and presented by intensifying watering strategy (see [9]).

Table 1: *Daily low, high, and amplitude of pavement temperature on July 7th, 8th, 10th, 11th, 20th and 22nd 2013.*

Date		Low (°C)	High (°C)	Amplitude (°C)
July 7th	(control)	26.0	39.9	14.0
July 8th	(watered)	25.3	33.7	8.4
July 20th	(control)	28.8	43.3	14.5
July 22nd	(watered)	29.7	36.6	6.8
July 11th	(control)	22.7	37.9	15.2
July 10th	(watered)	22.9	30.7	7.7

4. Discussion

The effect of pavement-watering on 5 cm pavement temperatures is clear: compared to control days, temperatures drop by an average 5.9°C in the afternoon and the morning temperature decrease is increased by 2.3°C and is prolonged until the beginning of pavement insolation. Furthermore, the daily temperature amplitude is nearly halved. Sensible heat storage by the pavement 5 cm below its surface is therefore offset by about five hours.

These findings compare well with previous work by Asaeda et al. [12], Kinouchi and Kanda [13] and Li et al. [14]. Indeed, Asaeda et al. studied a 30 cm thick slab of asphalt concrete in Japan in the suburban area of Greater Tokyo in nearly unmasked conditions instrumented with thermocouples at different depths including 5 cm [12]. In their paper, the authors report 5 cm temperatures ranging from 26° to 48°C, thus an amplitude of 22°C, for air temperatures ranging from approximately 23° to 35°C. No watering of the pavement slabs was conducted.Also in Japan, Kinouchi and Kandastudied a watered permeable pavement, alsoin nearly unmasked conditions,equipped with a pavement sensor at a depth of 5 cm[12]. Air temperatures on the reported days ranged from 20-23°C to 30°-35°C.The authors found daily low and high pavement temperatures in the order of 25°C and 40-45°C, similar to Asaeda et al.[12], in dry conditions, respectively. On watered days, these temperature extremes were reduced to 23°C and 35-38°C. Finally, Li et al.also study standard and pervious asphalt pavements in Davis, California[14]. Impervious and pervious pavement temperatures 6.5 cm deep are nearly identicalin dry conditions and range from roughly 25°C to 51°C for air temperatures between 16°C and 37°C. Watering the pervious pavements causes an initial 14°C drop in temperatures, followed by a steadier 5-7°C reduction compared to the dry impervious asphalt concrete.

The temperatures described in these papers are higher than our own.This islikely due to the absence of insolation masks and to generally warmer summertime weather conditions in the Greater Tokyo Area and California compared to Paris. In addition, the temperature trends reported by Kinouchi and Kanda after watering are very similar to ours,includingthe reduction in low and high daily temperatures as well as that of their amplitude from 15-20°C to 12-15°C on watered days compared to control days[13]. While watering reported by Li et al. causes similar temperature drops to our own during insolation[14], no significant change in pavement temperature amplitude is visible. These lower changes in daily temperature amplitude may becaused by reduced evaporation due to sprinkled water seeping deep into the pavement, where temperatures are too low for significant evaporation to occur. Overall, we conclude that our results are comparable with those of these authors.

In comparison to the 5 cm pavement heat flux and surface temperature observations reported in Hendel et al. [9], [10], no significant 5 cm temperature spikes are visible before or during afternoon watering. Pavement heat flux and surface temperature spikes were shown in those papers to be reliable indicators of surface drying.As long as the pavement is wet, evaporation occurs and surface temperatures and sensible heat flows remain low, as seen in those previous papers. Conversely, as soon as the pavement dries, evaporation stops and temperatures and heat flows return to their previous levels. It was therefore found that surface drying should be minimized to maximize cooling. As reliable indicators of surface drying, the spikes in 5 cm pavement heat flux and surface temperature proved relevant to optimizing the watering frequency to keep the surface wet between watering cycles.In the absence of such spikes, a similar analysis based on 5 cm pavement temperaturescannot be conducted.

The absence of spikes is caused by dampening of the temperature signalby the thermal inertia of the pavement's surfacecourse. Therefore, pavement temperature measurements below high-inertia surface courses cannot be used to improve the watering method. However, they may still be useful in the case of surface courses with low thermal inertia, although they will remain less accurate than pavement heat flux or surface temperature measurements.

For the purpose of optimizing a pavement-watering method, 5 cm pavement temperatures are no more practical than pavement heat flux measurements in the field, requiring the same invasive and costly construction work for sensor installation. Furthermore, the dampening caused by the surface course significantly reduces their accuracy, even in the case of low-inertia materials. Surface temperature measurements, which are much less affected by material inertia and are not nearly as invasive as below-surface pavement measurements, remain a better option for this purpose, as described by Hendel et al. [10].

5. Conclusion

The field study conducted on Rue du Louvre in Paris over the summer of 2013 has allowed us to expose the effects of pavement-watering on street temperatures at a depth of 5 cm. Temperatures in the afternoon were reduced by 5.9°C bypavement-watering. Morning low temperatures, reached at 8 am on control days, were maintained until the beginning of pavement insolation on watered days and were decreased by 2.3°C, considering 6 am temperatures. Sensible heat storage by the pavement 5 cm below its surface is therefore offset by about five hours.Finally, the low-high daily temperature amplitude was nearly halved by pavement-watering.

These results were found to be consistent with previous work. Unlike the case of pavement heat flux or surface temperatures, 5 cm temperatures were found unsuitable for pavement-watering optimization, unless the inertia of the surface course is low enough.

These findings provide additional information on the effects of pavement-watering in complex urban environments. Pavement surface temperature measurements remain the simplest and cheapest option to optimize pavement-watering. Further research may make the case for the use of below-surface temperature measurements in low-inertia materials such as granite pavers. The data and information presented here and in our previous work on surface temperatures and pavement heat flux may be of use to the urban modeling community seeking data for soil model validation [9], [10].

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References

[1] T. Kinouchi and M. Kanda, "An Observation on the Climatic Effect of Watering on Paved Roads," *J. Hydrosci. Hydraul. Eng.*, vol. 15, no. 1, pp. 55–64, 1997.

[2] H. Yamagata, M. Nasu, M. Yoshizawa, A. Miyamoto, and M. Minamiyama, "Heat island mitigation using water retentive pavement sprinkled with reclaimed wastewater," *Water Sci. Technol. a J. Int. Assoc. Water Pollut. Res.*, vol. 57, no. 5, pp. 763–771, Jan. 2008.

[3] R. Takahashi, A. Asakura, K. Koike, S. Himeno, and S. Fujita, "Using Snow Melting Pipes to Verify the Water Sprinkling's Effect over a Wide Area," in *NOVATECH 2010*, 2010, p. 10.

[4] J. Wei and J. He, "Numerical simulation for analyzing the thermal improving effect of evaporative cooling urban surfaces on the urban built environment," *Appl. Therm. Eng.*, vol. 51, no. 1–2, pp. 144–154, Mar. 2013.

[5] P. Maillard, F. David, M. Dechesne, J.-B. Bailly, and E. Lesueur, "Characterization of the Urban Heat Island and evaluation of a road humidification mitigation solution in the district of La Part-Dieu, Lyon (France)," *Tech. Sci. Méthodes*, no. 6, pp. 23–35 (in French), 2014.

[6] A. Lemonsu, R. Kounkou-Arnaud, J. Desplat, J. L. Salagnac, and V. Masson, "Evolution of the Parisian urban climate under a global changing climate," *Clim. Change*, vol. 116, no. 3–4, pp. 679–692, Jul. 2013.

[7] Météo France and CSTB, "EPICEA Project - Final Report," Paris, France (in French), 2012.

[8] M. Bouvier, A. Brunner, and F. Aimé, "Nighttime watering streets and induced effects on the surrounding refreshment in case of hot weather. The city of Paris experimentations," *Tech. Sci. Méthodes*, no. 12, pp. 43–55 (in French), 2013.

[9] M. Hendel, M. Colombert, Y. Diab, and L. Royon, "An analysis of pavement heat flux to optimize the water efficiency of a pavement-watering method," *Appl. Therm. Eng.*, vol. 78, pp. 658–669, Mar. 2015.

[10] M. Hendel, M. Colombert, Y. Diab, and L. Royon, “Improving a pavement-watering method on the basis of pavement surface temperature measurements,” *Urban Clim.*, vol. 10, no. December, pp. 189–200, Dec. 2014.
[11] M. Hendel, P. Gutierrez, M. Colombert, Y. Diab, and L. Royon, “Measuring the Effects of UHI Mitigation in the Field: Application to the Case of Pavement-Watering in Paris,” *Urban Clim.*, no. (under review), 2015.
[12] T. Asaeda, V. T. Ca, and A. Wake, “Heat storage of pavement and its effect on the lower atmosphere,” *Atmos. Environ.*, vol. 30, no. 3, pp. 413–427, Feb. 1996.
[13] T. Kinouchi and M. Kanda, “Cooling Effect of Watering on Paved Road and Retention in Porous Pavement,” in *Second Symposium on Urban Environment*, 1998, pp. 255–258.
[14] H. Li, J. Harvey, and D. Jones, “Cooling Effect of Permeable Asphalt Pavement Under Dry and Wet Conditions,” *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2372, no. -1, pp. 97–107, Dec. 2013.